DEVELOPMENT OF AN ADVANCED 50TH PERCENTILE MALE HEAD/NECK SYSTEM FOR APPLICATION TO CRASH TEST DUMMIES

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ABSTRACT

An advanced 50th percentile male mechanical head/neck system has been developed which is capable of duplicating the responses of human head/neck kinematics and dynamics during multi-directional impacts. The head/neck system was based on the head and neck originally designed for the THOR Alpha advanced frontal dummy. The new system can be utilized on the THOR dummy, but can also be directly retrofitted to the standard 50th percentile male Hybrid III dummy.

In this paper, an overview of the new head/neck system design is presented. Simulation methods utilized for design and validation purposes are discussed. Results of dynamic pendulum and multi-directional mini-sled tests are also provided. Finally, responses are compared with benchmark human volunteer data.

INTRODUCTION

The use of anthropomorphic test devices (ATD) or crash test dummies is a practical way to evaluate the safety of motor vehicles in a crash environment. Injuries to the human head-neck complex are commonly seen in vehicle crashes and may lead to serious to fatal consequences. In particular, the problem of deploying air bags in out-of-position environments is of special concern because of the potential for serious injury or even death (NHTSA, 2003). Therefore, there is a need to have a mechanical head/neck system with improved biofidelity, which can be implemented into current crash test dummies.

Over the years, different neck designs have been developed with various degrees of success. A neck developed by General Motors Corporation (Foster et al., 1977) is used in the current Hybrid III dummy. This neck meets the standard Mertz-Patrick corridors, which defines the moment acting at the occipital condyle joint as a function of the head angle relative to T1 (the first thoracic vertebra) (Mertz et al., 1973; Patrick and Chou, 1976). However, this neck does not exhibit good agreement with respect to head kinematics when compared to results from volunteers tests conducted at the Naval Biodynamics Laboratory (NBDL) (Ewing et al., 1975; Seemann et al., 1986). The NHTSA has been performing and funding research on improved mechanical neck systems for several years. A head-neck mechanical simulator, which included muscular effects, was developed by NHTSA in the early 1970s (Haffner and Cohen, 1973). In 1985, the Vehicle Research and Test Center (VRTC) of NHTSA developed an improved version of the head/neck simulator based on the same concept and presented the results at the 12th ESV (Mendis et al., 1989). One improvement in the mechanical head and neck developed by VRTC was to use a spring and cable system exterior to the neck to simulate human neck muscular contribution during impact. The spring/cable design was meant to reproduce the proper excursions and lag which were seen in the NBDL volunteer experiments (Klinich and Beebe, 1994). After the initial effort, the VRTC researchers developed several prototype neck designs and also formalized the performance criteria for biofidelic dummy necks during follow-up work. The final neck design in the series fabricated by the VRTC exhibited promising results relative to the performance criteria. However, this design was not suitable for retrofitting into a crash test dummy because of the size and location of the exterior spring/cable system.

In 1996, GESAC was funded by the NHTSA to adapt the VRTC design and develop a head/neck system which could be integrated into the NHTSA advanced frontal dummy, THOR (White et al., 1996), the latest revision of which is known as THOR Alpha (Haffner et. al, 2001). This neck was evaluated by several research institutes such as TNO and JARI (Hoofman et al., 1998) and the results indicated that the neck substantially satisfied the frontal and lateral flexion kinematic requirements. However, additional improvements to the neck were judged to be possible in the areas of including new biomechanical data, improved anthropometry and capability to adapt to other dummies. For example, neck extension experiments on volunteers have been conducted by several researchers in recent years (Davidsson et al., 1998; Ono et. al, 1999) and newly updated corridors have been developed according to these data. Another area of interest was in improving the anthropometry of the THOR neck. In the THOR Alpha neck, the joint between the seventh cervical vertebrae and the first thoracic vertebra (C7/T1) is not clearly delineated and it was thought that a properly defined location for C7/T1 would help in the definition of any injury assessment using THOR. In addition, a THOR neck that could retrofit into the standard Hybrid III dummy was thought to be practical. In order to meet these new design criteria, modifications to the THOR-Alpha neck were needed. In this paper, the modifications to the design of the THOR-Alpha neck for these purposes are discussed, which include design requirements, simulations, design, and preliminary tests.

DESIGN REQUIREMENTS

There are three major design requirements for the new neck, which are anthropometry, geometry constraints to retrofit to the Hybrid III dummy, and matching the human neck responses in kinematics and dynamics. Since the mechanical neck is used to represent a 50^{th} percentile male, the new neck needed to generally match the Advanced Anthropomorphic Test Dummy (AATD) landmarks developed by Schneider et al. (1983). For example, the joint between head and neck around occipital condyle (O.C.) and the junction between the neck and thoracic spine (C7/T1) are among these landmarks. In addition, because the neck is to be retrofitted to the Hybrid III neck, the current constraints in the Hybrid III head/neck complex have to be considered. These constraints include the length of the neck, a large horizontal offset from the neck base to the occipital condyle joint, and the location of the pitch change relative to the thoracic spine. Since the neck is meant to reproduce the response of a human neck under impact, the most important criterion is to match the dynamic and kinematic responses of the mechanical neck with the human responses. The main sources of human head/neck response requirements for the mechanical neck are listed in Table 1. The corridors define the trajectories of the head during dynamic impacts. The corridors will be plotted with the simulation results in the discussion of the preliminary simulations that follow. In addition, the Mertz corridors (Mertz et al., 1973; Patrick and Chou, 1976) which define the dynamic response of the neck, have been utilized as secondary requirements as well.

THOR-BETA NECK/HYBRID III RETROFIT

Based on the design requirements described in the previous section, a new neck was designed and fabricated. This neck is called the THOR-Beta neck and shown in the Figure 1.

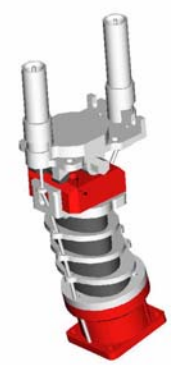

Figure 1. THOR-Beta neck.

Table 1. Sources of requirements

Test Condition		Sled Pulse	Tested by	Reference
Sled HyGe Test	Flexion	15g	NBDL	Thunnisen et al.(1995)
	Extension	4g~5g 3g~4g	JARI Chalmers University	Ono et al.(1999) Davidsson et al.(1998)
	Lateral	7g	NBDL	Wismans and Spenny (1983)
Strap Test	Out of Position	-	JARI and MCW	Ono et al. (2001)

When compared to the THOR-Alpha neck (White et. al., 1996), the new design includes several new features, which are listed as follows:

(1) 4 pucks

As discussed in the previous section, the distance from the O.C. to C7/T1 is a significant anthropometric dimension for the dummy neck design. By using a 4-puck design, the new neck agrees with the O.C.-C7/T1 length derived from NBDL tests and the T1 (the first thoracic vertebra) is located at the bottom of the neck column. (Figure 2)

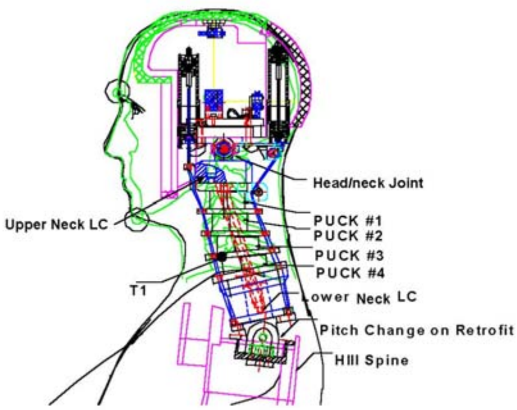

Figure 2. THOR-Beta neck overlaying the specifications for AATD

(2) Slightly inclined neck structure

One of the objectives for the new neck was to assume that it could be used with the Hybrid III dummy. Therefore, the new neck had to satisfy the design constraints in the current Hybrid III head-neck structure, which was described in the Design Requirements section. In order to do so, the new shape was modified with small angles in the bottom two of the four pucks (puck#3 and #4 in Figure 2). As a result, the top of the new neck is offset from the bottom. The gradual inclined design is different from the Hybrid III one-step change, and in this respect, the Beta neck partly mimics the curvature of the human neck structure.

(2) New puck shape to simulate extension stop

For the human neck, the responses in flexion and extension are different. In the original THOR Alpha design, neck extension stops were used to simulate this difference. The stop produced a relatively concentrated load, and a sharp transition in force and moment. In order to improve the smoothness of the response, the new design, shown in Figure 3, replaces the stops by adding a small wedge to the original elliptical puck. The wedge is made by cutting off material from the edge of a larger, elliptical puck.

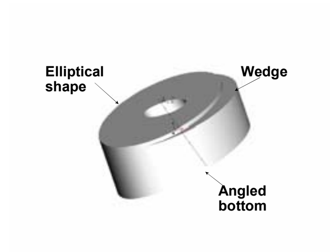

Figure 3. Puck with wedge

The behavior of the new puck under loading is shown in Figure 4. Because of the wedge, the stiffness at larger bending angles in extension is greater than in flexion.

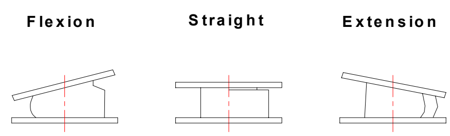

Figure 4. Kinematics of the new puck with wedge

(4) New spring with rubber tube insert.

In the original THOR neck spring-cable design, there were two spring-cable assemblies, one at the front and one at the rear of the neck. The springs are contained within aluminum tubes and both tubes are located inside the head. One limitation of the current design was that there would be a sharp increase in force after the spring bottomed out. Such an increase would not be biofidelic and may also damage the cable and create durability problems. A simple way to solve the problem is to reduce the stiffness of the springs and add a rubber tube within both springs (Figure 5). The combination of rubber and spring will reduce the sharp bottoming effect, make the response more biofidelic, and also possibly prevent possible cable damage.

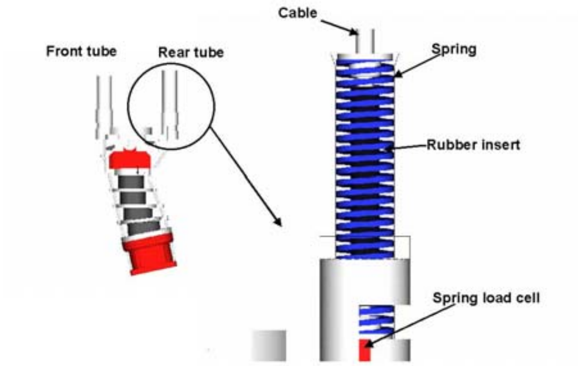

Figure 5. Spring with rubber insert

(5) New pitch change mechanism

A new pitch change mechanism was developed as an interface between the THOR beta neck and the Hybrid III spine. The pitch change mechanism is capable of rotating the neck relative to the thoracic spine every three degrees and rigidly fixing the neck at a given angle. A sketch of the pitch change mechanism with the THOR-Beta head/neck system is shown in Figure 6. There are four major parts in the mechanism: Pitch Base, Pitch Left, Pitch Right and Pitch Top. Pitch Top and Pitch Base are the interfaces to the THOR-Beta neck and the Hybrid III spine, respectively. Pitch Right is attached to Pitch Top and Pitch Left is attached to Pitch Base. The Pitch Right and Pitch Left consist of teeth arranged in a circle which can engage each other. With the new pitch change mechanism, the THOR-Beta neck can be easily retrofitted to the Hybrid III without any modification of the Hybrid III spine.

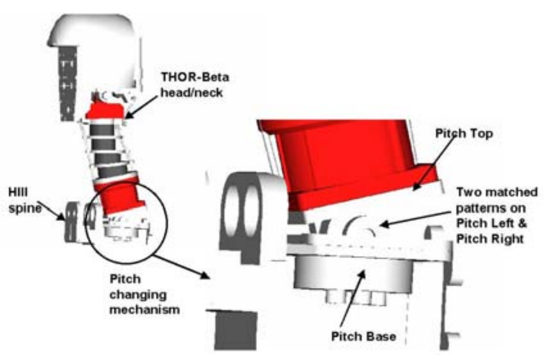

Figure 6. New pitch changing mechanism with THOR-Beta head/neck system

(6) Rubber bushing in the central cable

The THOR-Alpha neck does not allow for axial extension (Z direction). However, this kind of deformation may exist in the human neck during impact (Ono et al. 1999). Therefore, it was thought useful to modify the design to allow for such a deformation. A simple way to do this is to use a compressible material such as rubber to replace the current rigid Delrin spacer at the bottom of the central cable. Figure 7 shows the location of the compliant bushing.

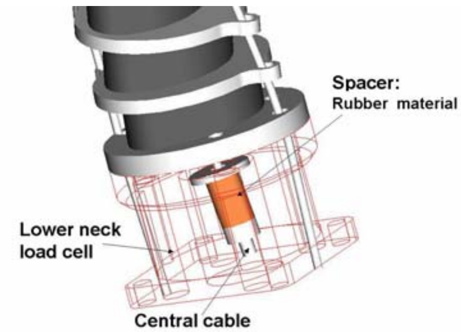

Figure 7. Location of rubber bushing

Apart from the above features, the instrumentation used with the THOR-Beta head/neck system is the same as its Alpha version. They are a nine-accelerometer-array system inside the head, five face load cells, upper and lower 6-axis neck load cells, two uniaxial spring load cells, and a potentiometer at the head/neck joint. The data from these transducers can be used to compute various head and neck injury parameters. For example, the upper and lower load cells are capable of measuring the neck loads, which include moment, shear force, and axial force. The neck load cell data along with the spring load cell and potentiometer data can be used to compute the total moment acting that the O.C. or N_{ij} both of which have been used as injury indices. These data can provide the information to evaluate the likelihood of neck injury in the crash environments such as air bag deployment or vehicle rollover.

SIMULATION

In order to validate the new design, simulations using the DYNAMAN model (Shams et al., 1992) were performed. These simulations of 15g frontal flexion, 7g lateral flexion, and 3g - 5g rear extension tests are based on the sources described in Table 1. The results for the simulations are shown in Figure 8, 9, 10,and 11, respectively.

For 15g flexion simulations, the head angle is inside the corridor and the head displacements (X and Z) are at the lower boundary of the corridors. For the 7g lateral simulation, the head angle is inside the upper boundary of corridors but the head Y and Z displacements are slightly short of the corridor. For the Chalmers' extension tests (Davidsson et al, 1998), results from the simulation show good correspondence with the X and Z displacements from the tests, but the simulation head angle is larger than the volunteers'. The reason probably is that the appropriate properties for the headrest used in the Chalmers' tests, which were not available. For the JARI extension tests (Ono et. al., 1999), the maximum head angle is around 35-50 degrees. On the other hand, the result from the simulation is around 55 degrees. That is close to the upper boundary from the JARI tests. In conclusion, the results from these three types of simulations show generally good agreement with the corridors.

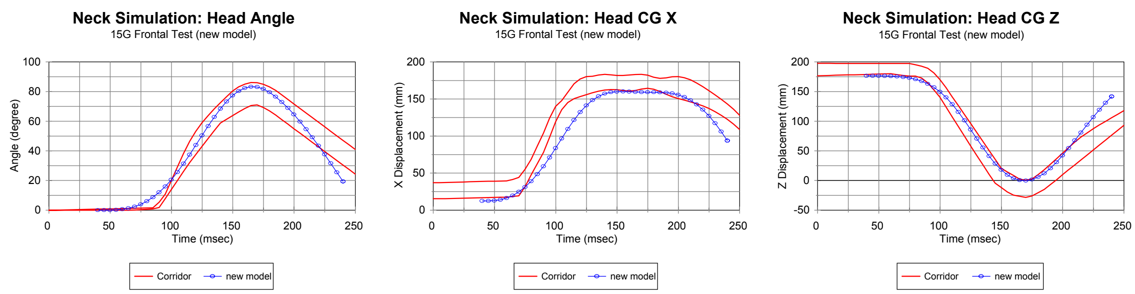

Figure 8. Simulation results in 15g flexion

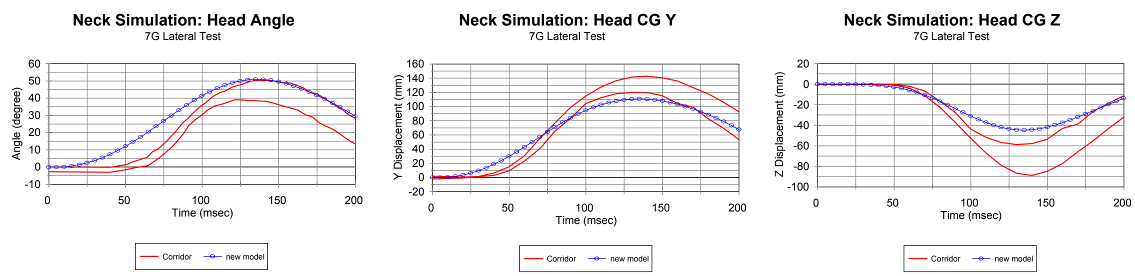

Figure 9. Simulation results in 7g lateral flexion

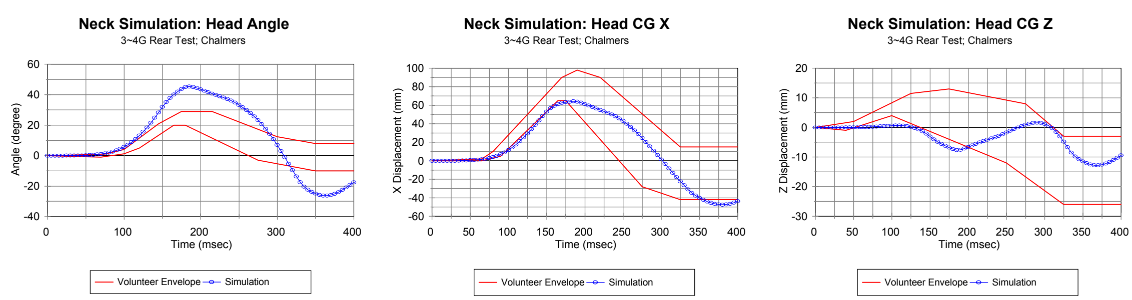

Figure 10. Simulation results in 3~4g extension (Davidsson 1998)

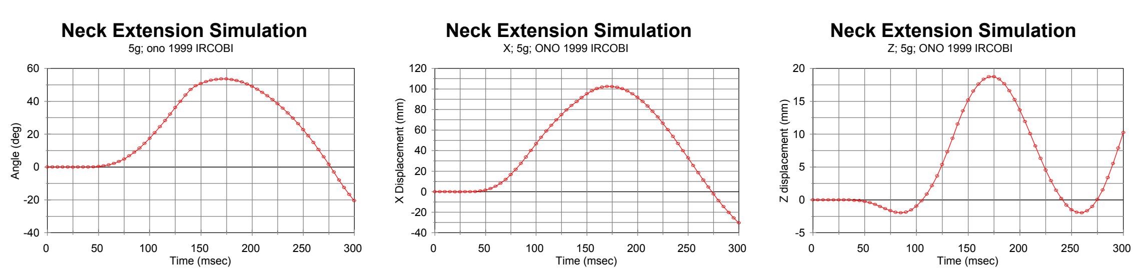

Figure 11. Simulation results in 4~5g extension (Ono et al.,1999)

Table 2. Simulation results for JARI strap tests

	Angle (degree)		Moment (N-m)		Shear Force (N)		Axial Force (N)	
	JARI	Sim	JARI	Sim	JARI	Sim	JARI	Sim
Chin upward	10~20 (200ms)	11 (130ms)	-3 (45ms)	-1 ~1 (20~ 100ms)	-30~30 (60~ 140ms)	-20~30 (28~ 130ms)	130 (50ms)	150 (25ms)
Chin rearward	-5~5 (50~ 150ms)	-3~7 (35~ 130ms)	6 (40ms)	3~ -2.5 (40~ 60ms)	60 (40ms)	170 (40ms)	30 (40ms)	120 (40ms)
Forehead	15~20 (200ms)	18 (125ms)	*	-2.1 (80ms)	30 (25ms)	60 (100ms)	30 (25ms)	50 (200ms)

* not available

In addition, a preliminary simulation was performed for the strap neck tests (which was meant to simulate out-of-position air bag impacts) conducted by Ono et al. (2001). The setup for the JARI volunteer strap test is depicted in Figure 12.

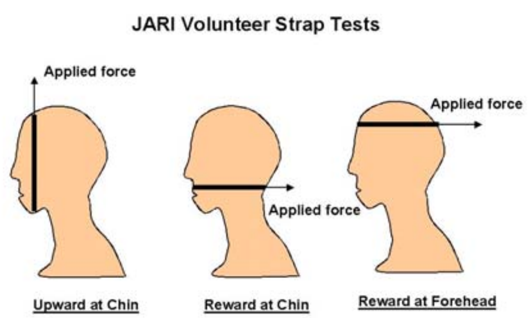

Figure 12. Setup for JARI volunteer strap tests

In the graph, the forces were applied in three different locations (upward at chin, reward at chin, and reward at forehead). The peak of the applied force for these strap tests at JARI was 150 N and the time period for this load was around 50ms. In the simulation, a single load, whose peak value and time duration are the same as the JARI volunteer tests, was applied perpendicular to chin or forehead of the DYNAMAN head/neck model. Both results from the simulation and JARI volunteer strap tests are compared in Table 2.

The results from the simulation of the strap tests with the new neck design were encouraging. Especially for the kinematics at the rearward chin tests, the THOR-Beta head according to the simulation was rotating in both flexion and extension, which was similar to the volunteer strap tests (Figure 13). The results of the simulations are summarized as follows:

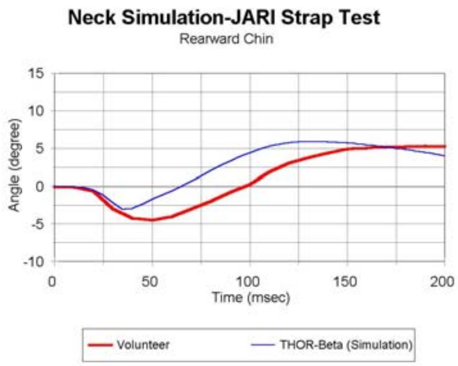

Figure 13. Head angle for strap testing simulation (Rearward Chin)

(1) Upward at Chin:
Kinematics: Extension occurred during the entire period; the peak angle from the simulation (11.5 degree) was close to the volunteer but the unloading part was faster than volunteer. This is attributed to the observation that the rubber neck posseses less hysteresis than the human.
Force & Moment: There was good agreement for both shear and axial forces (Fx, Fz); for the moment, although the value was close, it was hard to compare because the magnitude was small (peak for the volunteer's test around 3 N-m).

(2) Rearward at Chin:
Kinematics: The head rotated in flexion first; then in extension; this was similar to the volunteer results.
Force (Fx,Fz) & Moment: Both forces were higher than the volunteer but the shape was similar. For the moment, there were good agreements.

(3) Rearward at Forehead:
Kinematics: Extension during the entire period; the peak (19 degree) was also close to volunteers' results, but the unloading part was early.
Force (Fx,Fz) & Moment: Detailed results from volunteers for this series of tests were not available; therefore, there was no comparison possible.

These were preliminary simulations, but they indicated that the neck should qualitatively match the output seen from volunteers.

PRELIMINARY DYNAMIC TESTS

In order to verify the new head/neck system, both mini-sled and dynamic pendulum tests were conducted.

Mini-sled Tests

A mini-sled was used to verify the performance of the full Hybrid III dummy retrofitted with the new THOR-Beta head/neck system. The mini-sled is a inclined ramp with a single seat sliding on a track and is shown in Figure 14. It is a slightly modified version of a device the NHTSA has used to show the benefits of wearing seat belts and is known as the Convincer. The travel distance for the seat is around 2.3 meters and the angle for the incline is 15 degrees. Rubber pads are used to stop the sled and generate the deceleration. The deceleration is adjustable by using additional bungee cables. In the mini-sled tests, the THOR-Beta head/neck system was retrofitted to the rest of the Hybrid III dummy by using the new pitch-changing mechanism. Tests, both in flexion and extension, were conducted for this series of experiments. The dummies in these tests were restrained by both shoulder and lap belts.

Figure 14. Mini-sled device used for evaluating neck response.

Target markers were placed at the major landmark points such as head CG, O.C., and T1 and a high-speed camera was used to record the motion. In order to compare with the Hybrid III neck, the regular Hybrid III dummy was tested under the same conditions, i.e. both in flexion and extension.

<u>Flexion</u>

In flexion, the peak sled deceleration was around 15g for both the THOR-Beta and Hybrid III necks. The time duration of the pulse was around 60 ms. The maximum displacements of the head were obtained by analyzing the high-speed camera film. The maximum displacement of the head occurred around 140 ms for the THOR-Beta neck and 110 ms for the Hybrid III neck. Figure 15 shows the head/neck at the time of maximum displacement for both necks. Table 3 compares the head CG displacements of the

THOR-Beta and Hybrid III necks, which were derived by digitizing the pictures from the high-speed camera. The THOR-Beta neck shows greater flexion under this setup (15g and 60ms deceleration pulse) than the Hybrid III neck.

THOR-Beta

HIII

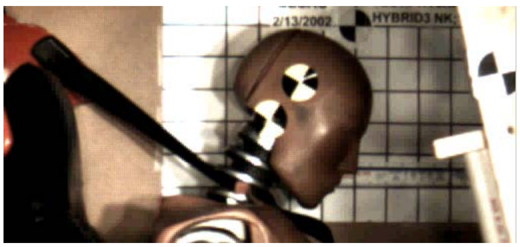

Figure 15. Comparison of THOR-Beta and Hybrid III head/neck systems at maximum displacements in flexion

Table 3. Comparison of maximum displacements between THOR-Beta and HIII neck in flexion

	Time (ms)	Max. Head Angle (deg)	Max. Head CG Displacement X (mm)	Max. Head CG Displacement Z (mm)
THOR-Beta	140	45	157	71
HIII	110	27	110	27

Extension

By turning the seat 180 degrees, extension tests were also conducted on the mini-sled. The peak deceleration in extension was between 5-7g and the time duration between 60~70 ms. The peak was slightly higher (and duration shorter) than the tests performed at JARI (4g; 100 ms) because of the limitation in replicating the JARI deceleration profile. Pictures at the time of maximum head displacement are shown in Figure 16. The maximum displacements for both necks occurred about the same time (160 ms). Table 4 compares the displacement results for both THOR-Beta and Hybrid III necks. The maximum head angle relative to T1 for this series of tests is around 49 degrees for THOR-Beta neck and 45 degrees for Hybrid III neck. The result for maximum head angle from the corridor developed by JARI is from 39 degrees to 52 degrees. It is thought that the reason the peak head extension angle is at the higher end of the corridor is due to the higher peak deceleration used in the tests. The tests were meant to provide a qualititative evaluation of the performance of the neck. Tests which fully replicate the JARI test conditions will be performed in the near future.

THOR-Beta

HIII

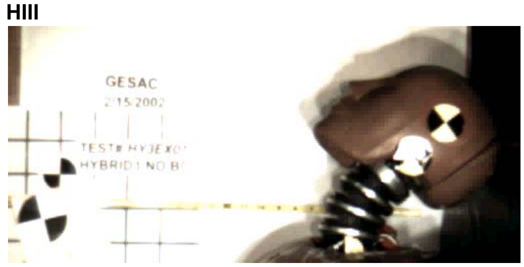

Figure 16. Comparison of THOR-Beta and Hybrid III necks at maximum displacements in extension

Table 4. Comparison of maximum displacements between THOR-Beta and HIII neck in extension.

	Time (ms)	Max. Head Angle (deg)	Max. Head CG Displacement X (mm)	Max. Head CG Displacement Z (mm)
THOR-Beta	160	49	158	46
HIII	160	45	160	42

Dynamic Pendulum Tests

Tests in frontal flexion, extension, and lateral flexion using a head/neck pendulum were performed with the new neck. In these tests, the head-neck assembly was dropped from a specified angle into a contact plate which is covered with foam. The peak deceleration is controlled by choosing different drop angles for the pendulum arm. The peak decelerations for the impact pulses in all three directions for this series of tests are shown in Table 5. The main purpose for the tests was to evaluate the kinematics rather than the maximum sustainable loading.

Table 5. Deceleration for dynamic pendulum tests

	Flexion	Lateral	Extension
Peak Deceleration (g)	27	17	4
Duration (ms)	40	45	120

Since the current THOR-Alpha neck has been shown to have reasonable agreement with the human corridor (Hoofman et. al., 1998), it was used to develop a baseline for comparing the new Beta neck. Both the Alpha and Beta necks were tested in these preliminary studies. In addition, the Hybrid III head/neck was tested in this series of experiments as well. Results for these three head/neck systems are described in the following section.

Moment at O.C.

In the dummy neck, loads are normally measured by using the neck load cell. The measurement from the neck load cell represents the response at a point offset from a point representing O.C. in dummy. Thus a correction to the total moment has to be made due to the contribution of the shear force. In the case of the THOR necks, forces due to the two spring/cables would also contribute to the moment at O.C. In the tests conducted at GESAC, the computations for the total moment at the O.C. are carried out by a program called THORTEST, which was developed to post-process various instrumentation data collected by THOR (NHTSA, 2002).

Table 6. Peak moment at O.C. for pendulum tests

	THOR-Beta (N-m)	THOR-Alpha (N-m)
Flexion	62 (68ms)	68 (68ms)
Lateral Flexion	35 (67ms)	35 (66ms)
Extension	-24 (125ms)	-19 (125ms)

Results from this series were computed by using this program and the peak moments at O.C. are given in Table 6 for both the THOR-Alpha and Beta necks in flexion, lateral flexion, and extension. It is seen that the peak moments at O.C. are similar and the timing is close. The results suggest that both necks have similar moment responses at O.C. The head rotation angle was obtained by digitizing the high-speed camera output. The moment at the O.C. was plotted against head angle and compared to the biomechanical corridors (Mertz et al., 1973; Patrick and Chou, 1976). These plots are shown in Figures 17, 18, and 19. The graphs show that the THOR-Beta neck responses fall within the corridors in all three directions. For lateral flexion, a small part of the moment vs. angle curve goes outside the corridor. These tests were conducted without the neck skin and without a shoulder. Thus the moment does not take into account the contribution due to the interaction of the neck flesh with the shoulder flesh which would occur in the case of the volunteer at the higher flexion angles. This interaction would increase the stiffness at the higher angles.

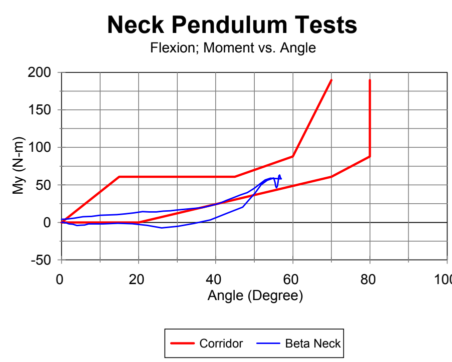

Figure 17. Moment vs. angle in flexion

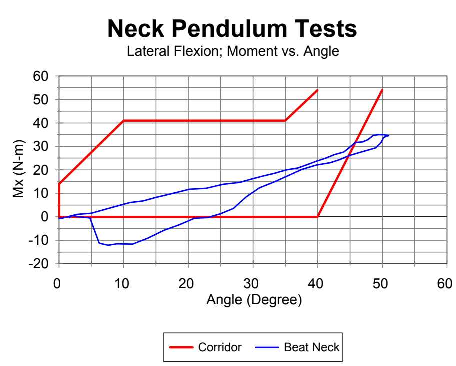

Figure 18. Moment vs. angle in lateral flexion

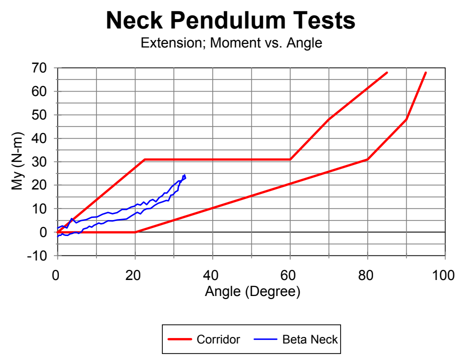

Figure 19. Moment vs. angle in extension

Kinematic Response

The kinematic responses were obtained by digitizing the pictures from the high-speed camera (at an interval of 2 msec). The results for the three necks in flexion and lateral flexion are shown in Table 7 and Table 8, respectively.

Table 7. Peak kinematic response in flexion for pendulum tests

	Time (ms)	Max. Head Angle (deg)	Max. Head CG Displacement	
			X (mm)	Z (mm)
THOR-Beta	74	55	172	132
THOR-Alpha	72	64	202	142
HIII	50	54	123	77

Table 8. Peak kinematic response in lateral flexion for pendulum tests

	Time (ms)	Max. Head Angle (deg)	Max. Head CG Displacement	
			Y (mm)	Z (mm)
THOR-Beta	60	51	168	79
THOR-Alpha	60	55	184	82
HIII	44	36	125	42

From the tables, it is seen that there is a decrease in the maximum head angle and maximum head displacement with the THOR-Beta neck as compared to the current THOR-Alpha neck. Previous testing (Hoofman et. al., 1998) indicated that the kinematic response of the THOR-Alpha neck put it at the higher end of the corridor for head angle and head X displacement. Thus the stiffer response of the Beta neck is expected to move the response in the right design direction. When compared to the Hybrid III neck, the results show that both THOR necks are more flexible than Hybrid III in both frontal and lateral flexion. Also, the time to reach the peak values for the THOR neck is longer than the Hybrid III neck in these two directions. In addition, some rotation about the Z-axis (i.e. the about the neck vertical axis) was observed for the THOR-Beta neck during the lateral tests due to its inclined structure. In the volunteer tests, there is significant torsional motion (Wismans and Spenny, 1983). With the straight necks found in the THOR-Alpha and in the Hybrid III, the torsional effect was minimal. Though the slightly inclined structure in the THOR-Beta neck generates some torsion, it is still lower than that seen in the human volunteers.

Table 9 shows the kinematic results from the extension tests. In this case, the THOR-Beta neck rotates more than the Alpha neck. In addition, the peak head rotation angle and head C.G. displacements for Hybrid III are slightly higher than corresponding values for the THOR-Beta neck in this direction. The times to reach the peak value in extension are also similar for the three necks.

Table 9. Peak kinematic response in extension for pendulum tests

	Time (ms)	Max. Head Angle (deg)	Max. Head CG Displacement	
			X (mm)	Z (mm)
THOR-Beta	126	35	101	20
THOR-Alpha	116	21	110	10
HIII	124	33	90	2

DISCUSSION

A new head-neck system for THOR has been fabricated and the new neck is called the THOR-Beta neck. The principal reasons for modifying the existing Alpha neck are:

1. Improve anthropometry to make it closer to the human neck structure
2. Improve biofidelity to make the neck more useful in out-of-position air bag tests
3. Add capability to retrofit to Hybrid III.

The new Beta neck contains several new features:

1. 4 rubber pucks (instead of five in the Alpha neck)
2. Introduction of angled rubber pucks to generate a slightly inclined neck
3. Modified neck spring to prevent sharp responses which are not humanlike.
4. New puck shapes to respond differently in flexion and extension.
5. Rubber bushing to allow axial extension.
6. A mechanism to allow a simple retrofit to the Hybrid III spine.

Design parameters, such as the size and shape of the rubber pucks and the material characteristics were obtained using lumped-mass simulations with the DYNAMAN model (Shams et. al, 1992). The simulations indicated that the new neck should agree well in kinematics with the volunteer corridors in all three directions, namely frontal flexion, extension, and lateral flexion.

A series of dynamic tests were performed under two test conditions. The first, using a head/neck pendulum tested the kinematics of the THOR-Beta head/neck system only and compared them to that of the current THOR-Alpha head/neck and the Hybrid III head/neck. The second, used a mini-sled to test the response of a Hybrid III dummy which had been retrofitted with the new head and neck. The results from these tests were also compared with those of the current THOR-Alpha and Hybrid III dummies.

Repeated dynamic tests were conducted with the new neck. Figures 20 and 21 show the O.C. moment responses in frontal and lateral flexion in repeated tests. The graphs indicate that the new neck has good repeatability. Durability was also good, with the neck being subjected to pendulum tests without failure over 30 times. The tests showed good agreement with the THOR-Alpha neck as well. From the pendulum test results, it was seen that in both frontal and lateral flexion, the THOR-Beta neck had slightly lower peak head angular motion and head displacement than the THOR-Alpha. If this change in response is borne out in regular sled-tests to be conducted, then it would make the Beta neck more biofidelic than the Alpha. From the pendulum tests, it is also seen that both the THOR-Alpha and Beta necks produce significantly greater head motion than the Hybrid III neck in frontal and lateral flexion and approximately the same motion in extension.

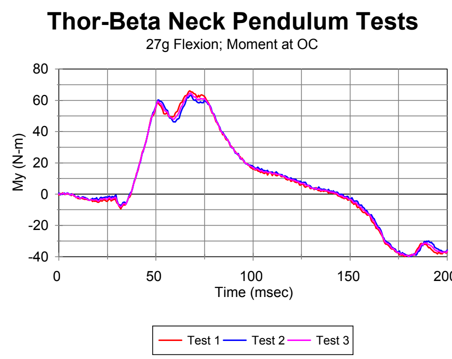

Figure 20. O.C. moment results for repeated pendulum tests in flexion

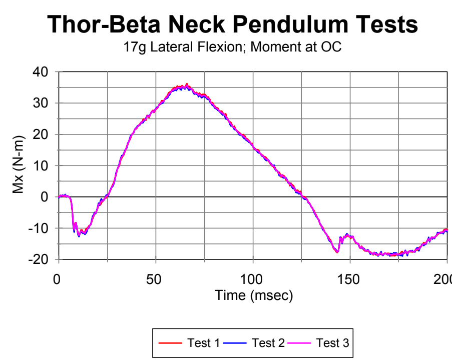

Figure 21. O.C. moment results for repeated pendulum tests in lateral flexion

CONCLUSION

The improved kinematics of the THOR-Beta neck should make it a better device for use in air bag testing. The preliminary testing using the head/neck pendulum and the mini-sled indicated that the kinematics using the THOR-Beta neck would be an improvement over the Alpha neck. Testing on a standard HyGe sled is being planned to confirm the results. These tests will test the new head/neck system in an environment similar to that used for the

NBDL volunteers. The capability to retrofit to the existing Hybrid III dummy would also make the new neck useful in a wider range of tests.

A new cam/rubber mechanism design is being considered for the O.C. in the THOR-Beta neck. The modification is meant to improve its response in out-of-position air bag testing. The modification involves the redesign of the shape of rubber that limits the movement of the head in frontal flexion and extension. The new design will make it easier to tune the moment-angle response. The NHTSA is currently evaluating biomechanical data regarding the response at O.C. under dynamic loading and coming up with a representative moment-angle characterization at the joint. Once the characterization is complete, the intention is to implement it using the new rubber stop design.

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